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Reducing the Asphalt PG Grade in 4.75mm Sand Mixes Evaluated Using Strength-type Tests

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Introduction

The 4.75mm mix has been used in hot mix asphalt (HMA) pavements, on a limited basis, in Illinois for several years. It has been constructed in at least half of the State's 9 districts. It is used primarily as a level binder in overlay applications and is currently designed using PG 76-28 asphalt, with an asphalt content typically over 8%. As a result, this is an expensive mix. Consequently the question has been asked, "Since this is an expensive mix, can the PG grade be reduced to save some cost without sacrificing stability?" This report summarizes the laboratory testing performed to answer that question.

4.75mm Sand Mix Background

The 4.75mm mix was designed to be used primarily as a level binder in applications where a new HMA surface lift is to be placed over the existing pavement. It was not designed to be used as a surface course due to its low friction properties. It may, however, have limited application as a surface mix in low traffic speed applications.

The 4.75mm mix level binder lift is typically placed ¾ inch thick which meets the "3 times the nominal maximum aggregate size" requirement and therefore the necessary density for optimum stability and durability can be achieved. The currently used standard 9.5mm level binder, when placed in a ¾ inch thick lift, does not meet that requirement.

The PG 76-28 currently specified requires a high polymer content. This high polymer content provides the high elastic recovery thought necessary to retard reflective cracking. This mix also uses a high percentage of manufactured sand to provide for mix stability.

This mix has low water permeability values due to the small aggregate size, high minus #200 content, and the high asphalt content. Even at otherwise low density values very little water passes through this mix.

The hope originally was that this mix would retard reflective cracking. Use of this mix is showing that, while it may slow down the propagation of reflective cracks, it does not work in all cases. The benefit of retarding reflective cracking can likely be optimized by choosing pavements to overlay where the condition of the underlying structure is in reasonable condition.

Since this mix is not as effective at retarding reflective cracking as originally hoped, it made sense to investigate the possibility of reducing the PG grade to make the mix more economical. This was accomplished by conducting tests on the 4.75mm mix using several different types of equipment.

Equipment

Five different pieces of equipment, designed to evaluate the strength of HMA, were used in the testing. These five pieces of equipment/tests were:

1. The Asphalt Pavement Analyzer (APA)
   - with hoses,
   - with a steel wheel,
2. The Pine Rut Tester,
3. Stability,
4. The Indenter.

The Asphalt Pavement Analyzer (APA)

The APA is a loaded wheel tester that, for most testing, uses a pressurized rubber hose between the loaded wheel and the compacted HMA specimen(s). The standard APA is equipped with 3 sets of loaded wheels and pressurized hoses. Each wheel and hose set tests either one 75mm tall beam specimen or two 75mm tall gyratory compacted specimens. A typical test is run for 8,000 cycles. The rut depth of the specimen is measured manually, with a digital micrometer, and also automatically using transducers housed in the load cylinders with the results displayed on the computer screen. The Bureau of Materials and Physical Research (BMPR) has owned an APA since 1996. The APA is shown in Picture 1.

Picture 1

Picture 2

BMPR has modified an old, worn high density polyethylene sample mold to allow the option of APA testing with a steel wheel riding directly on the asphalt specimen in a Hamburg-type test (Picture 2). A test is typically a maximum of 20,000 cycles, or less, if the mix reaches a maximum rut depth of approximately 18 mm in fewer cycles.

The Pine Rut Tester

The Pine Rut Tester is another loaded wheel-type test (Picture 3). BMPR had a Pine Rut Tester in-house for several months in 2004-2005, on loan from Pine Instrument Company, and ran over 100 tests with it. In this test, the 150mm gyratory specimen is sandwiched between 3 steel wheels which rotate the specimen, shown in Picture 4. These wheels load the specimen on its side, or circumference, as it rotates. (In other loaded wheel tests and on the roadway, the HMA is both compacted and loaded on its end.) The typical test is run for 3,000 load cycles.

This is a harsh test. Unlike the other tests, and in-place pavement, the HMA is always under load (on the 3 contact points) in the Pine Rut Tester. It is never able to rest, without any load applied.

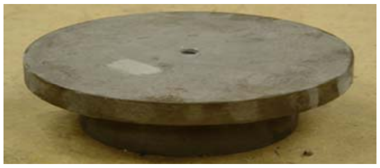
Picture 3

Picture 4

The Indenter

The Indenter is a 6-inch diameter steel plate with a 4-inch diameter by 1-inch high cylinder on one end, shown in Picture 5. The overall height of the Indenter is 36.7mm. The idea for the Indenter was developed at Iowa State University and was described in a Ph.D. thesis entitled, “A Really Simple Performance Test.”

Picture 5 (Top) & Picture 6



The concept for the Indenter is based on the idea that HMA consolidation occurs in 2 distinct phases, the construction phase and the performance phase.

The construction phase occurs at a high temperature and the 4.75mm mix is compacted to about 6% air voids (a dense graded mix is typically compacted to about 7% air voids) to represent in-place pavement density. In the field, this is accomplished with a roller while in the laboratory a gyratory compactor is used.

The performance phase happens at a lower temperature. In the field, this is as a result of many traffic load cycles over time.

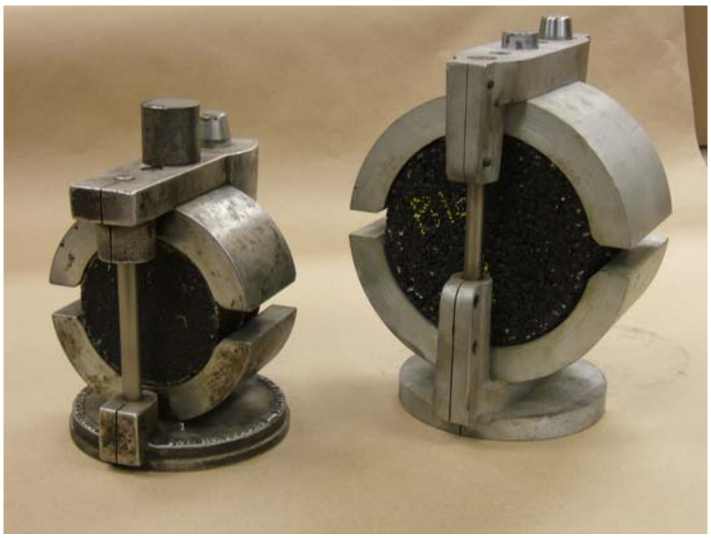
In the lab, following compaction the specimen and mold are cooled to ambient temperature for 1 hour. Then the specimen and mold are reheated to 64°C for 2 hours. After 2 hours, the Indenter which has been pre-heated to 64°C is placed in the gyratory mold, on top of the specimen. The specimen with the Indenter is then compacted for an additional 300 gyrations. This is intended to simulate the deformation of the HMA under traffic at an in-service temperature. The height per gyration is recorded which represents the deformation. After the test, the specimen is extruded from the mold. A specimen that has been tested in the Indenter is shown in Picture 6.

The Indenter is the least expensive test used in the study, with a cost of less than $100 for the materials needed to make the device.

<u>The Stability Test</u>

Historically, Marshall Stability, on 4-inch diameter specimens, has been regarded as a pretty good indicator of the potential performance of a mix. However, Stability testing was not incorporated into Superpave. With a breaking head for 6-inch specimens and a reasonable correlation factor to relate 6-inch specimens with 4-inch specimens, Stability testing could be readily available to any lab conducting testing on HMA. BMPR is conducting testing to develop a reasonable factor to correlate the stability of 6-inch specimens with 4-inch specimens. A 4-inch breaking head and a 6-inch breaking head are shown in Picture 7 holding the corresponding 4-inch and 6-inch specimens.

<u>Picture 7</u>



Testing

BMPR conducted testing, using the 5 lab tests listed above, to determine the effect on the strength of the Illinois 4.75mm mix when the PG grade of the asphalt binder is reduced. The testing took place from the summer of 2004 to the summer of 2005.

Two different Illinois 4.75mm mix designs were used, one each provided by IDOT District 3 and District 5. The first was #83Bit020L with 72.5% FM20, 24.0%FM02, 3.5% MF01, and 8.7% AC. The second was 35Bit0817 with 80.4% FM20, 18.1% FM02, 1.5% MF01, and 8.6% AC. Both mixes had been used previously in the field.

All the aggregates were fractionalized to reduce testing variability. Because of small amounts of some specific size fractions, re-sampling of the same aggregates was necessary to have sufficient material to do all the testing.

4 different asphalt PG grades were each used with each of the 2 mix designs. The grades were PG 64-22, PG 70-22, PG 76-22, and PG 76-28. All the PG 64-22 was sampled from Marathon at Meredosia. The first sampling of the other 3 grades came from Emulsicoat in Urbana. When the testing scope grew and re-sampling became necessary, Emulsicoat no longer had PG 76-28 available. The PG 70-22, PG 76-22, and PG 76-28 that was used for the remainder of the project came from Seneca Petroleum in Lamont. Additional sampling of the PG 76-28 from Seneca was necessary

to complete the testing using the APA with a steel wheel and the Indenter. Although the final PG 76-28 sample passed all required PG asphalt tests, several previous sampling attempts did not pass the required PG asphalt tests and were not used for the 4.75mm sand mix in this study.

All the testing was conducted at a temperature at, or near, 64°C which is the seven-day high temperature average for the majority of Illinois. Note that none of the testing was done to evaluate the mix at the PG low temperature of 22°C or 28°C.

Table 1 below shows the test temperature and target air voids for each test for the 4.75mm mix.

Table 1

Test	Test Temperature	Target Air Voids	Test Condition
APA with Hoses	64°C	6.0 ± 0.5	Dry
APA with Steel Wheel	50°C	6.0 ± 0.5	Submerged
Stability	60°C	2.5 ± 0.5	Submerged 30-40 minutes prior to Test
Pine Rut Tester	50°C	2.5 ± 0.5	Submerged
Indenter	64°C	6.0 ± 0.5	Dry

Table 2 shows the number of specimens tested and the number of individual tests conducted for each of the 5 tests and for each PG grade for each of the 2 mixes. A total of 263 specimens were tested in this project with 207 individual tests being conducted.

Stability testing generally is conducted at the design air void content which is 2.5% for these 2 mixes. In this testing, an additional set of 4-inch specimens was compacted at 7% air voids and tested to see if the change in PG grade at higher air voids followed a similar pattern as the specimens compacted at design air voids.

Table 2

Number of Specimens Tested (Number of Tests)

					Stability		
	APA with Hoses	**APA with Steel Wheel**	**PINE**	**Indenter**	**4" @ 7%**	**4" @ 2.5%**	**6" @ 2.5%**
D3 76-28	6 (1)	4 (2)	3 (3)	4 (4)	6 (6)	6 (6)	3 (3)
D3 76-22	6 (1)	4 (2)	3 (3)	3 (3)	7 (7)	6 (6)	3 (3)
D3 70-22	6 (1)	4 (2)	3 (3)	3 (3)	6 (6)	6 (6)	3 (3)
D3 64-22	6 (1)	4 (2)	6 (6)	4 (3)	6 (6)	6 (6)	3 (3)
D5 76-28	6 (1)	4 (2)	5 (5)	3 (3)	6 (6)	6 (6)	3 (3)
D5 76-22	6 (1)	4 (2)	5 (5)	3 (3)	6 (6)	6 (6)	3 (3)
D5 70-22	6 (1)	4 (2)	5 (5)	3 (3)	6 (6)	6 (6)	3 (3)
D5 64-22	6 (1)	4 (2)	6 (6)	3 (3)	6 (6)	6 (6)	3 (3)
Totals	48 (8)	32 (16)	36 (36)	26 (26)	49 (49)	48 (48)	24 (24)
	263 (207)						

Table 3 contains the average results for each of the 2 mix designs at each PG grade with the APA and the Pine Rut Tester. Table 4 contains the average results for Stability testing for each of the 2 mix designs at each PG Grade. Most of the following graphs and analysis are taken from the average values in these 2 tables.

Table 3

Sand Mix Data Summary, APA and PINE Rut Tester

	APA with Hoses @ 8000 cycles		PINE Rut Tester			APA Steel Wheel			
						Manual Rut (mm)	Automatic Rut (mm)		Auto
	APA Manual Average Rut (mm)	APA Automatic Average Rut (mm)	PINE: Avg Rut (mm)	PINE: # of Cycles	PINE: # of Cycles per mm of Rut	APA S.W. Rut (Man Avg)	APA S.W. Rut (Auto Avg)	APA S.W. # of Cycles	APA S.W. # of Cycles per mm of Rut
D3 64-22	16.6	15.7	10.4	658	63	17.6	18.1	2569	142
D3 70-22	9.7	8.6	10.4	3000	289	17.7	18.6	3689	199
D3 76-22	6.5	5.6	2.7	3000	1092	17.2	17.6	4012	227
D3 76-28	6.3	5.3	1.6	3000	1848	17.2	18.1	2363	130
D5 64-22	11.8	10.9	8.5	806	94	17.4	18.2	3729	205
D5 70-22	7.8	7.2	11.8	1657	141	17.8	18.5	6335	342
D5 76-22	5.6	4.7	2.0	3000	1496	17.3	18.1	5644	311
D5 76-28	4.0	3.5	1.4	3000	2203	16.8	18.1	4286	237

Table 4

Sand Mix Data Summary, Stability Tests

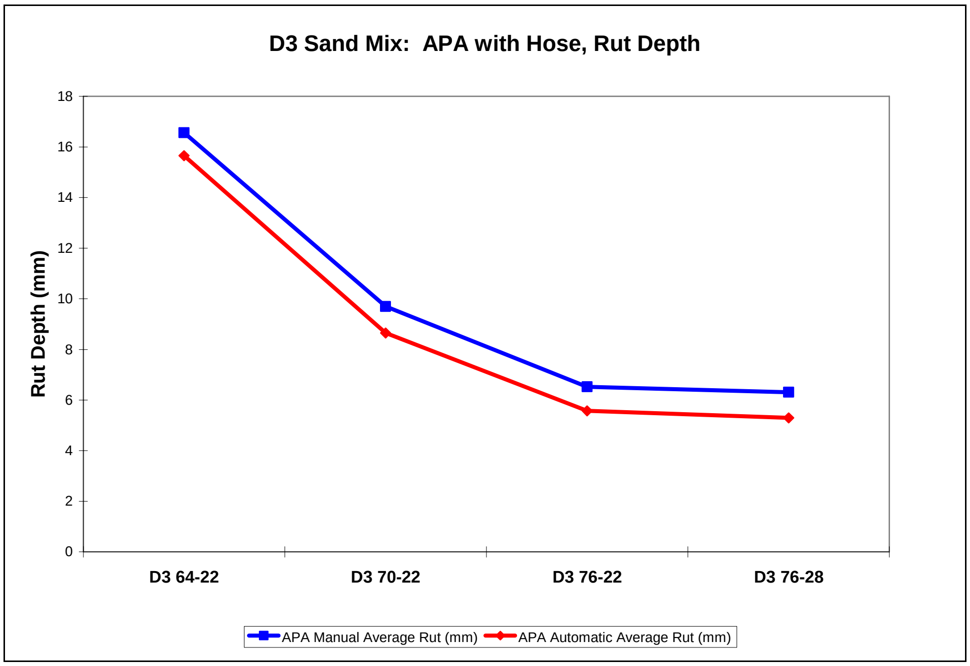
	Stability Testing					
	4" Stability @ 7% Voids		4" Stability @ 2.5% Voids		6" Stability @ 2.5% Voids	
	4" Avg Stability (7%)	4" Avg Voids (7%)	4" Avg Stability	4" Avg Voids (2.5%)	6" Avg Stability	6" Avg Voids (2.5%)
D3 64-22	1642	6.8	2296	2.3	5200	2.4
D3 70-22	1788	6.8	3038	2.3	6325	2.3
D3 76-22	1939	6.6	3383	2.4	8058	2.4
D3 76-28	1804	7.3	3308	2.6	7450	2.5
D5 64-22	1867	6.9	3171	3.0	6633	2.8
D5 70-22	2054	6.7	3817	2.6	7567	2.6
D5 76-22	2271	6.6	4025	2.7	8067	2.4
D5 76-28	2279	6.5	4008	2.9	7967	2.3

Observations and Evaluation

The average results from the District 3 mix for each of the 5 tests are shown in graphs 1 to 5.

Graph 1 shows the rut depth in the APA with rubber hoses for each of the 4 PG grades tested. Both the manual and the automatic reading were measured. The largest rut depth is from the specimens with PG 64-22 asphalt. A significant decrease in rut depth occurs when PG 70-22 is used. Another sizable decrease is seen when the PG grade is increased to 76-22 and a slight decrease occurs when PG 76-28 is used.

Graph 1

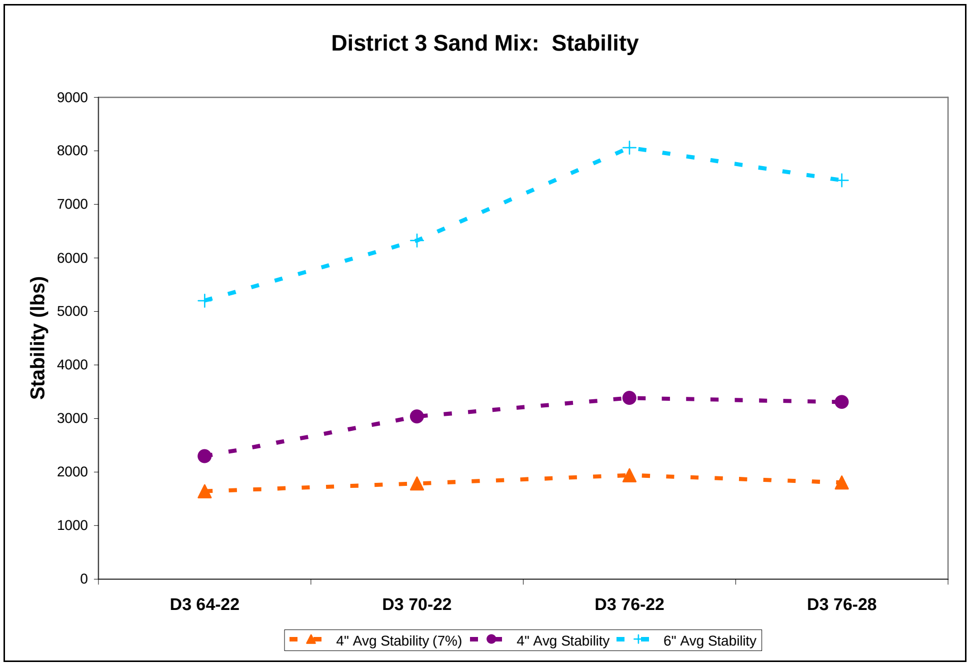


Graph 2 shows the stability values for the 4 different PG grades for 4-inch diameter specimens at 7% and 2.5% air voids as well as 6-inch diameter specimens at 2.5% air voids.

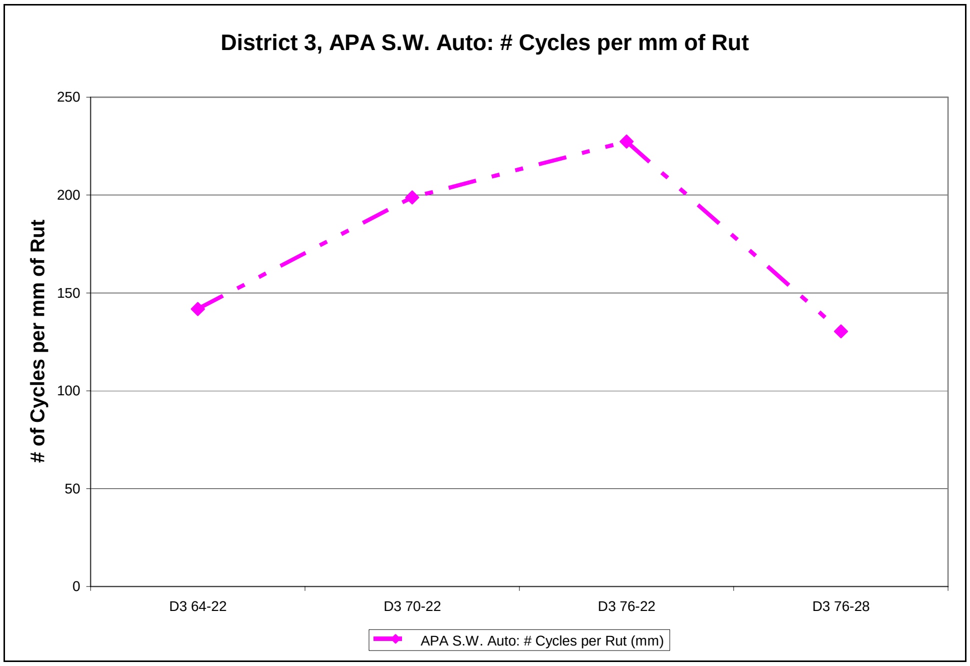
The stability increases, for all 3 groups of specimen size and air voids, when the PG grade is increased from 64-22 to 70-22. The stability also increases for all 3 groups when the grade is increased from PG 70-22 to PG 76-22. The increases in stability are greater for the specimens compacted to design air voids than for the specimens compacted to 7% air voids, even though the general trend is similar.

When the PG grade is increased from 76-22 to 76-28, the stability values all go down somewhat. This probably occurs because of the base asphalt. PG 76-22 begins with a PG 64-22 base asphalt material to which polymer is added. This increases the PG high temperature 2 grades from 64 to 76. On the other hand, PG 76-28 begins with a softer base asphalt, probably a PG 58-28, to which polymer is then added. This increases the PG high temperature 3 grades from 58 to 76. The stability test is probably sensitive to the softer base asphalt.

Graph 2



Graph 3

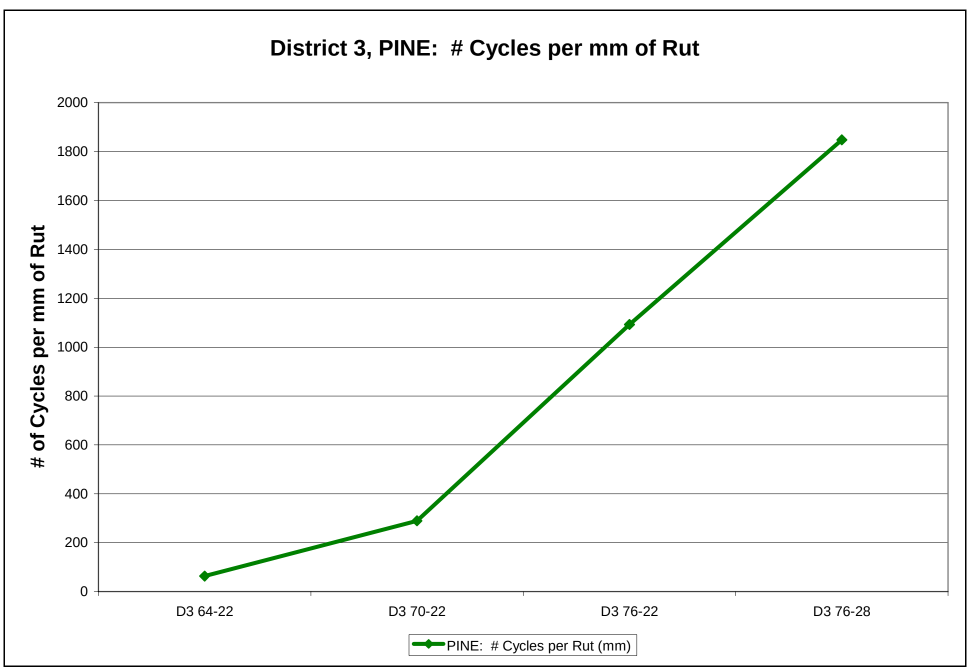


Graph 3 shows the APA with a steel wheel. The maximum rut depth, in mm, at the end of the test and the number of load cycles to reach that rut depth were both recorded. To simplify the graphical evaluation, a single value was calculated by dividing the number of cycles by the rut depth.

The pattern with this test is similar to the one seen for the stability testing. The number of cycles per mm of rut depth increases significantly when the PG grade is increased from 64-22 to 70-22 and again from PG 70-22 to 76-22. When the PG grade is increased from 76-22 to 76-28, however, the number of cycles per mm of rut depth drops dramatically to a value less than when PG 64-22 was used. This is quite likely because the APA with steel wheels is also sensitive to the softer base asphalt grade.

Graph 4 shows the results from the Pine Rut tester with the number of cycles per mm of rut depth (this test also measured both maximum rut depth and number of cycles). There is an increase in the number of cycles per mm of rut depth each time the PG grade is increased with the most dramatic increases occurring when the PG grade is increased from 70-22 to 76-22 and then again from 76-22 to 76-28.

Graph 4



The results for the Indenter are shown in Graph 5. The initial height includes the 36.7mm height of the Indenter and a standard 115mm gyratory specimen.

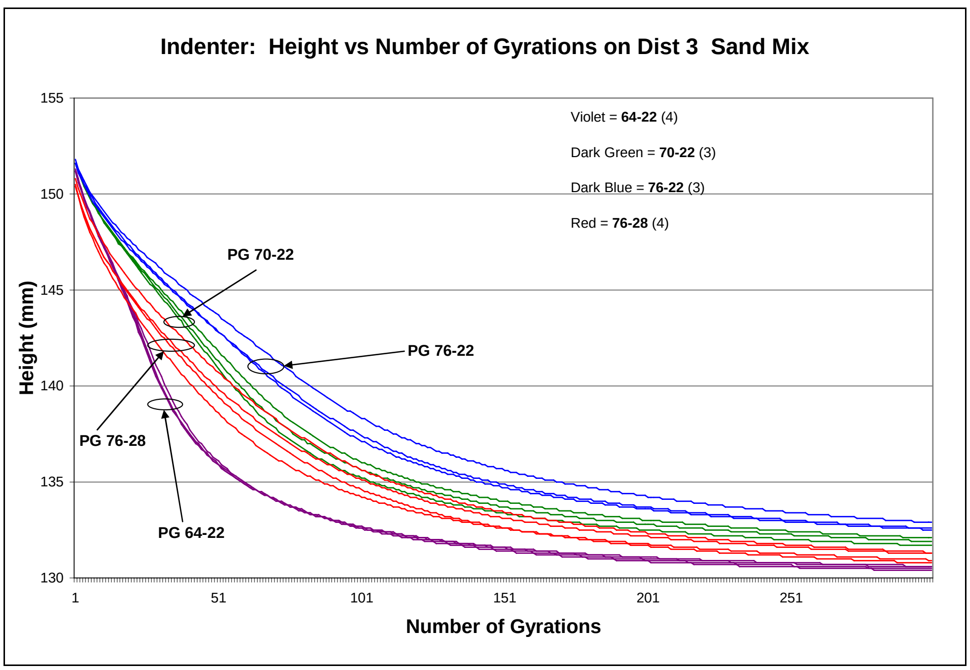
The 4 specimens with PG 64-22 are shown with the violet line. These specimens deform quickly under the force of the Indenter and at approximately 50 gyrations the rate of deformation becomes considerably slower. Most likely, at this point, most of the additional reduction in height can be attributed to lowering of the voids in the specimen.

The 3 specimens with PG 70-22 are shown with the green line. These specimens deform slower than the specimens with PG 64-22. The rate of deformation changes at around 80 gyrations at a height about 5 mm greater than where the rate of deformation slowed for the PG 64-22.

The 3 specimens with PG 76-22 are shown with the blue line. These specimens deform even slower than the specimens with PG 70-22. The rate of deformation changes at around 115 gyrations at a height about 1 to 2 mm greater than where the rate of deformation slowed for the PG 70-22.

The 4 specimens with PG 76-28 are shown with the red line. For the first 10 to 15 cycles these specimens deform at about the same rate as the specimens with PG 64-22. For the rest of the test, these specimens deform at about the same rate as the specimens with PG 76-22, except that the change in rate occurs at about 65 gyrations instead of around 115 gyrations.

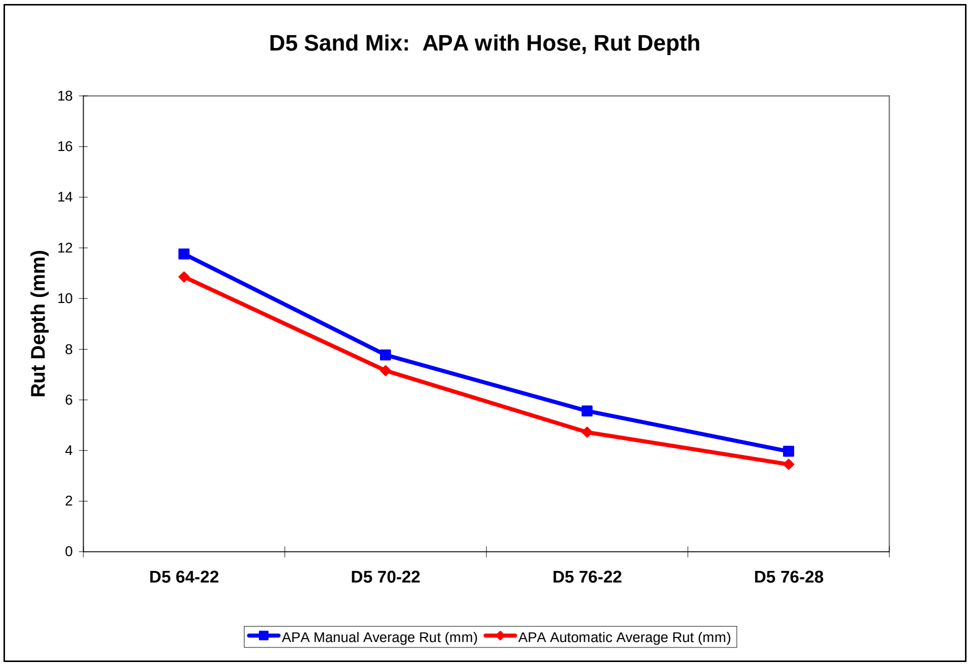
Graph 5



The average results from the District 5 mix for each of the 5 tests are shown in graphs 6 to 10.

Graph 6 shows the rut depth in the APA with rubber hoses for each of the 4 PG Grades tested. Both the manual and the automatic reading were measured. The largest rut depth is from the specimens with PG 64-22 asphalt. A significant decrease in rut depth occurs when PG 70-22 is used. Another sizable decrease is seen when the PG grade is increased to 76-22 and a slight decrease occurs when PG 76-28 is used.

Graph 6

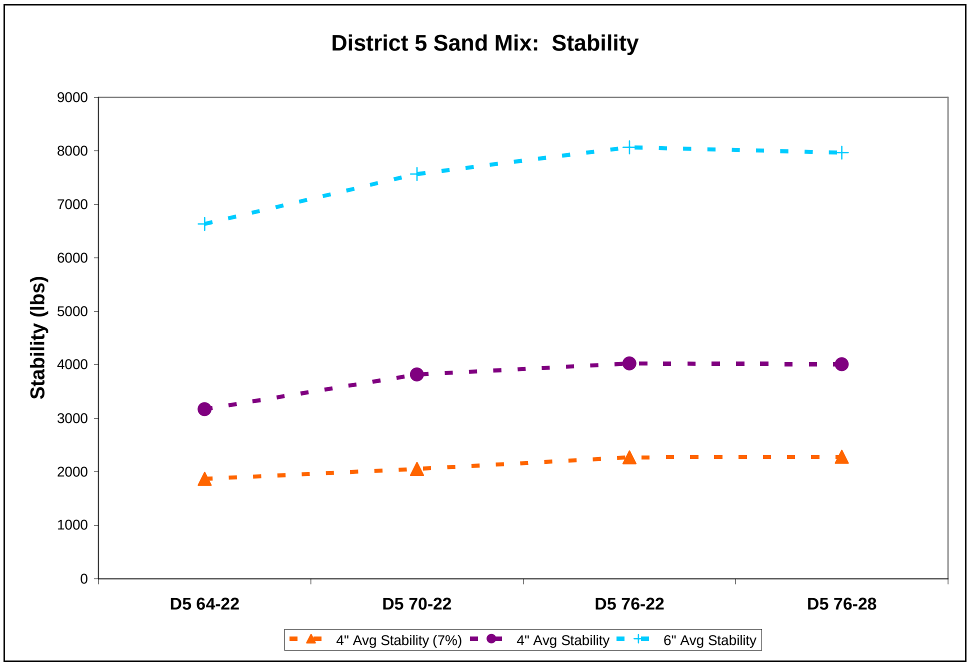


Graph 7 shows the stability values for the 4 different PG grades for 4-inch diameter specimens at 7% and 2.5% air voids as well as 6-inch diameter specimens at 2.5% air voids.

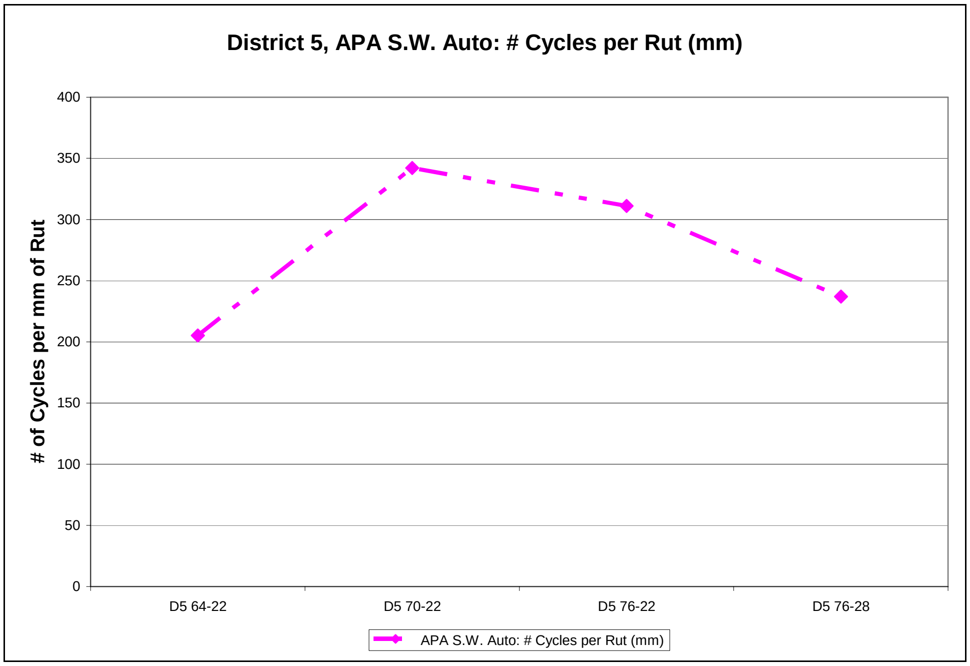
The stability increases, for all 3 groups of specimen size and air voids, when the PG grade is increased from 64-22 to 70-22. The stability also increases for all 3 groups when the grade is increased from PG 70-22 to PG 76-22.

When the PG grade is increased from 76-22 to 76-28, the stability values from the specimens compacted to design air voids go down somewhat while the stability value from the specimens compacted to 7% air voids increases very slightly. The decrease in the stability values of the specimens compacted to design air voids is most likely attributable to the softer base asphalt as described for the stability results for the District 3 mix.

Graph 7



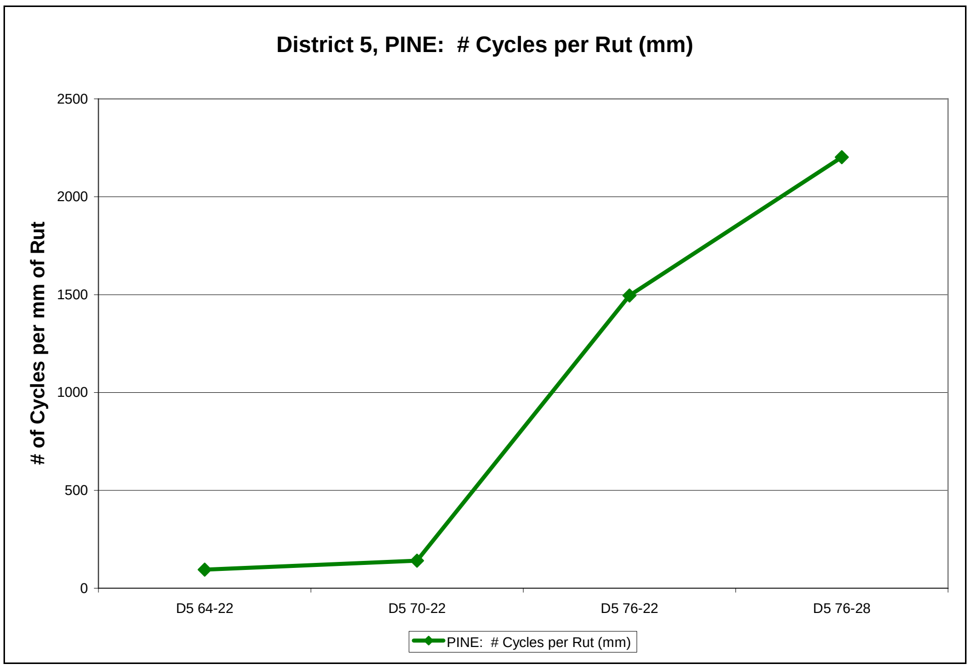
Graph 8



Graph 8 shows the APA with a steel wheel. The number of cycles per mm of rut depth increases significantly when the PG grade is increased from 64-22 to 70-22. When the grade is increased again from PG 70-22 to PG 76-22, the number of cycles per mm of rut depth drops by about 14%. When the PG grade is increased from 76-22 to 76-28, the number of cycles per mm of rut depth again drops again (by almost 34%).

Graph 9 shows the results from the Pine Rut tester with the number of cycles per mm of rut depth. There is an increase in the number of cycles per mm of rut depth each time the PG grade is increased with the most dramatic increases occurring when the PG grade is increased from 70-22 to 76-22 and then again from 76-22 to 76-28.

Graph 9



The results for the Indenter are shown in Graph 10. The initial height includes the 36.7mm height of the Indenter and a standard 115mm gyratory specimen.

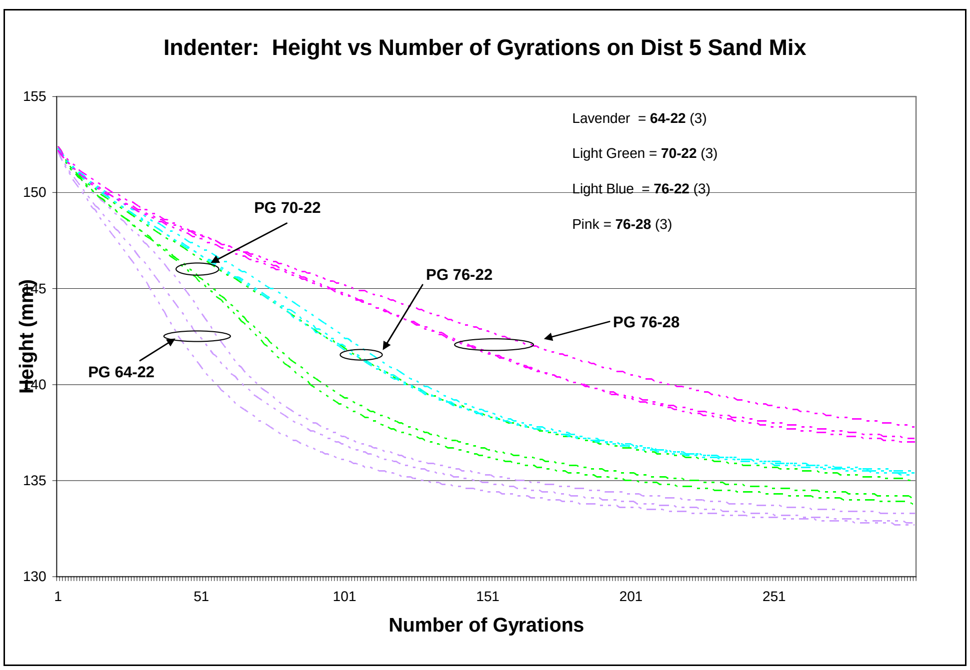
The 3 specimens with PG 64-22 are shown with the lavender line. These specimens deform fairly quickly under the force of the Indenter and at approximately 75 gyrations the rate of deformation becomes considerably slower. Most likely, at this point, most of the additional reduction in height can be attributed to lowering of the voids in the specimen.

The 3 specimens with PG 70-22 are shown with the light green line. These specimens deform slower than the specimens with PG 64-22. The rate of deformation changes at around 110 gyrations at a height 1 or 2 mm greater than where the rate of deformation slowed for the PG 64-22 asphalt.

The 3 specimens with PG 76-22 are shown with the light blue line. These specimens deform even slower than the specimens with PG 70-22. The rate of deformation changes at around 145 gyrations at a height about 1 to 2 mm greater than where the rate of deformation slowed for the PG 70-22.

The 3 specimens with PG 76-28 are shown with the pink line. The rate of deformation is relatively constant throughout the entire test, possibly changing slightly at about 225 gyrations. The final height is 2 to 3 mm higher than the final height of the specimens with PG 76-22. The rate of deformation of the PG 76-28 for the District 5 mix is less than the rate of deformation of the PG 76-28 for the District 3 mix.

Graph 10



Asphalt Costs

The cost of asphalt per ton was quoted at 3 different times, between March 2003 and July 2005, by several suppliers and is shown in Table 5. These costs were reasonably accurate estimates at that point in time by that particular supplier. They have very likely changed since that time, especially considering the conditions affecting the petroleum industry. However, the relationship between the costs of the different PG grades is important and it is assumed to still be comparable.

The cost of asphalt, per ton of mix, was calculated by using the average cost per ton of asphalt (see average costs in Table 5) multiplied times the average percent of asphalt in the two IL-4.75 mixes tested (8.65%). The costs shown in Table 5 are strictly material costs and do not include other costs such as those connected with production of the mix and construction of the pavement.

Table 5

Asphalt Cost

PG Grade	06/14/05, Bill Pine, Emulsicoat	03/14/03, Koch & Seneca (costs from Aeronautics)	07/20/05, Hugh Chapman, Seneca	Avg Cost per ton ($)	Cost of Asphalt per ton of Mix ($)
64-22	$180	$175	$170	**$175**	**$15.14**
70-22	$250	$270	$230	**$250**	**$21.63**
76-22	$280		$250-260	**$265**	**$22.92**
76-28	$300		$270	**$285**	**$24.65**

The cost increase when using these estimates, both in dollars and in percent, of changing from one PG grade to a different grade is shown in Table 6. The greatest increase in cost of $6.49 per ton of mix occurs when increasing the PG grade from 64-22 to 70-22. Increasing the grade from PG 70-22 to PG 76-22 costs an additional $1.30 per ton of mix and increasing the PG grade from 76-22 to 76-28 adds $1.73 to the cost of a ton of mix.

Table 6

Difference in Cost of Asphalt, per ton of mix, using different PG Grades			
From	**To**	**Cost Increase ($)**	**Cost Increase (%) Compared to 64-22 Cost)**
64-22	70-22	$6.49	42.9
64-22	76-22	$7.79	51.4
64-22	76-28	$9.52	62.9
70-22	76-22	$1.30	8.6
70-22	76-28	$3.03	20.0
76-22	76-28	$1.73	11.4

Comparison of Costs with Average Test Values

The values listed in table 7 are the averages of results from the 2 mixes tested. The Average Stability value is the average of all the individual stability results (4-inch specimens at 7% voids, 4-inch specimens at 2.5% voids, and 6-inch specimens at 2.5% voids) for each PG grade tested. These average test results along with the estimated cost of asphalt per ton of mix are used in Graphs 11 to 15. These graphs summarize the testing and compare the change in the asphalt costs to the change in mix strength, based on this testing. The goal of this comparison is to help determine the potential benefit on mix performance by increasing the PG grade of the asphalt.

Table 7

PG Grade	**Avg APA Rut Depth (mm)**	**Average Stability (lbs)**	Avg APA Steel Rut Depth (mm)	Avg APA Steel # of Cycles	**Avg APA SW # of Cycles per mm of Rut**	Avg PINE Rut Depth (mm)	Avg PINE # of Cycles	**Avg PINE # of Cycles per mm of Rut**	**Cost of Asphalt per ton of Mix ($)**
64-22	**13.7**	**2978**	17.8	3149	**177**	9.5	732	**77**	**$15.14**
70-22	**8.3**	**3528**	18.1	5012	**276**	11.1	2328	**210**	**$21.63**
76-22	**5.6**	**3872**	17.6	4828	**275**	2.4	3000	**1262**	**$22.92**
76-28	**4.8**	**3822**	17.6	3325	**189**	1.5	3000	**2010**	**$24.65**

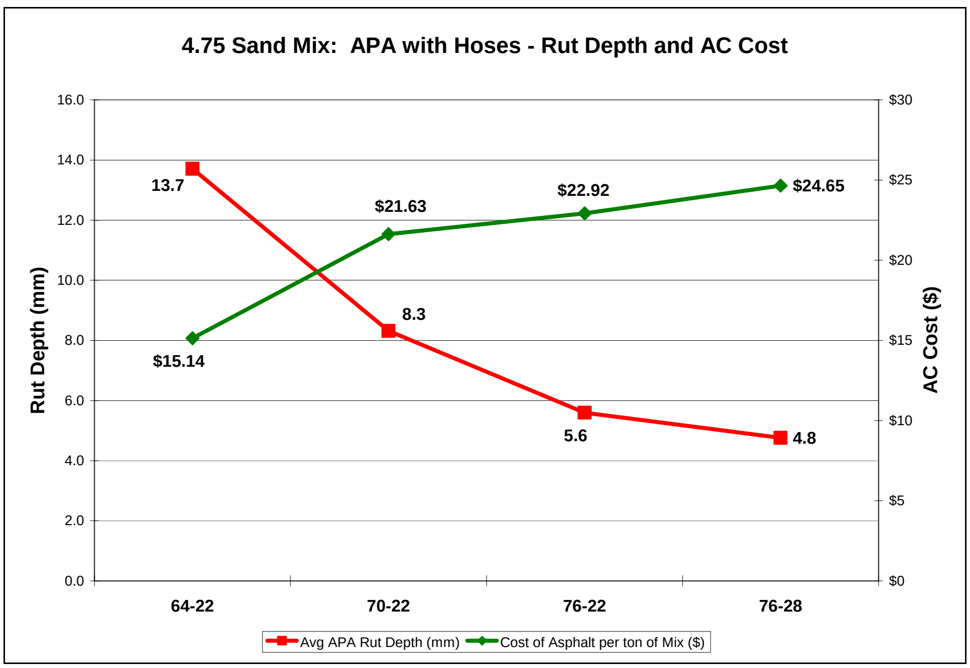
Graph 11 shows the average of manual and automatic rut depth values in the APA with hoses for the 2 mix designs used in the study and compares those readings with the asphalt cost per ton of mix.

The greatest decrease in rut depth occurs when the PG grade of the asphalt is increased from 64-22 to 70-22. The greatest increase in cost of asphalt per ton of mix also occurs with this increase in PG grade.

A significant decrease in rut depth occurs when the PG grade of the asphalt is increased from 70-22 to 76-22. The smallest cost increase corresponds with this increase in PG grade.

When the grade of the asphalt is increased from 76-22 to 76-28, a decrease in the rut depth corresponds with a moderate cost increase.

Graph 11



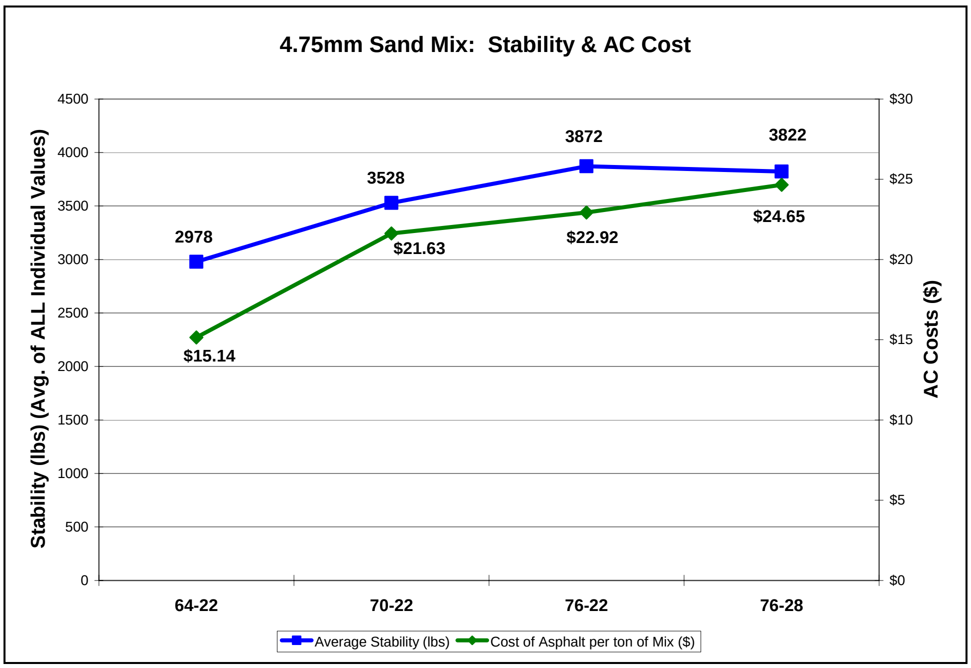
Graph 12 shows the average of all the stability test results for the 2 mix designs that are used in the study and compares those readings with the asphalt cost per ton of mix.

The stability values increase significantly when the PG grade of the asphalt is increased from 64-22 to 70-22 and from 70-22 to 76-22. These values correspond with increases in cost of asphalt per ton of mix.

When the grade of the asphalt is increased from 76-22 to 76-28, the stability value decreases somewhat while the cost per ton of asphalt shows a moderate increase.

Note that the minimum Marshall stability requirement for Type I, Type II, and Type III mixes was 2000 lbs, 1700 lbs, and 1500 lbs, respectively. Therefore all the stability results from the sand mix testing are "good" values, well above the minimum requirement.

Graph 12

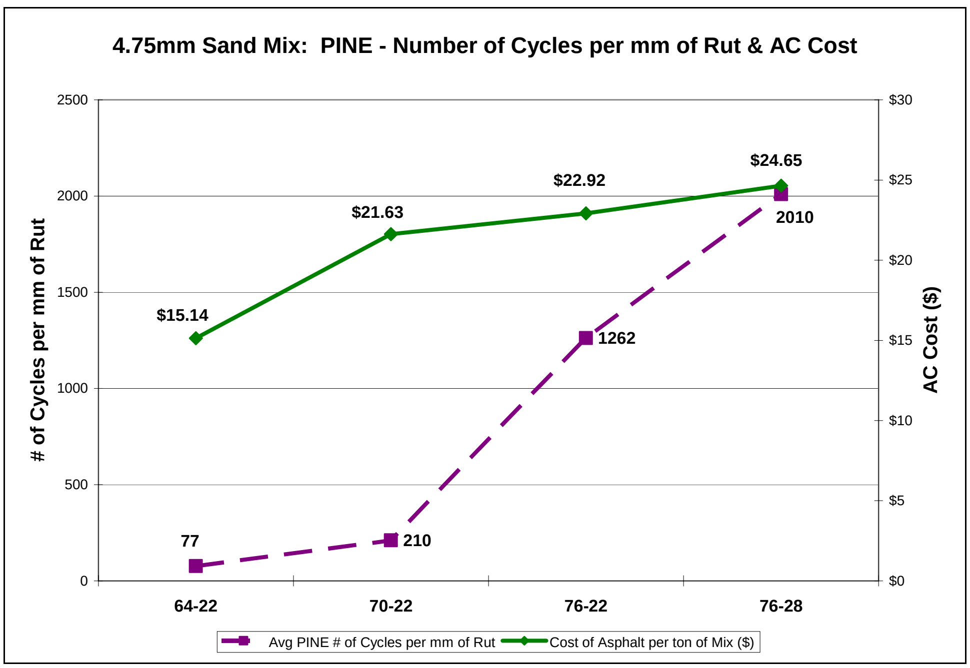


Graph 13 shows the number of cycles per mm of rut depth in the Pine Rut Tester. This graph includes the average value of all the tests for both mix designs for each PG grade tested.

When the asphalt grade is increased from PG 64-22 to 70-22 an increase in about 130 cycles per mm of rut depth occurs, the least change out of all the grade changes. This increase in cycles per mm of rut depth corresponds with the largest cost increase per ton of asphalt.

When the PG grade is increased from 70-22 to 76-22 and from 76-22 to 76-28 the cycles per mm of rut depth increase dramatically. Each of these increases in cycles per mm of rut depth can be compared with moderate increases in asphalt costs per ton of mix.

Graph 13



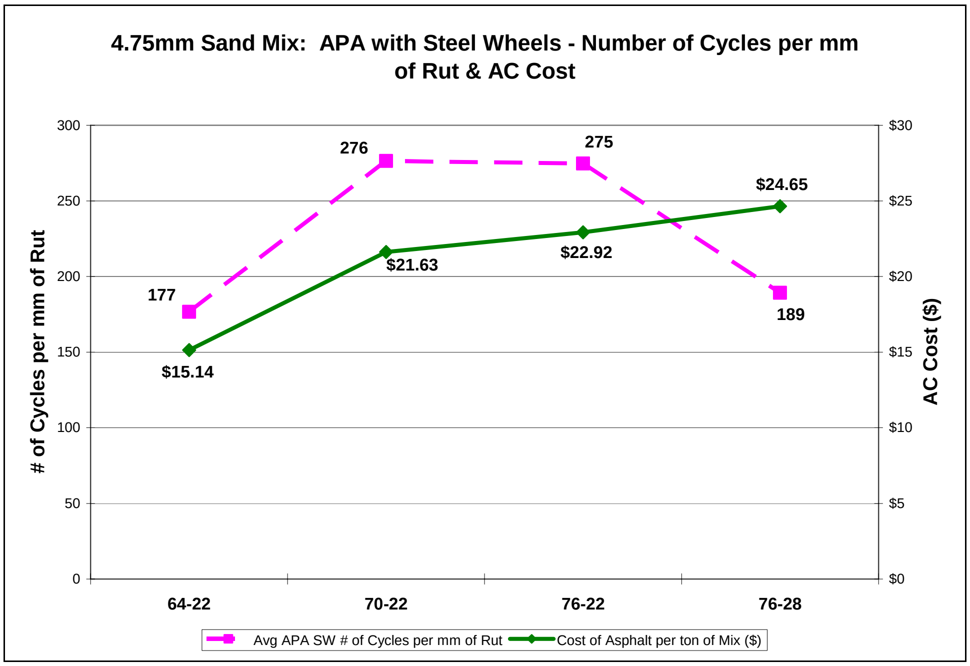
Graph 14 shows the average of all the tests for each PG grade with the APA using a steel wheel for both mix designs.

The most dramatic increases for both the number of cycles per mm of rut depth and for the cost of asphalt per ton of mix occur when the grade is increased from PG 64-22 to PG 70-22.

When the PG grade is increased from 70-22 to 76-22 the number of cycles per mm of rut stays basically the same while the cost increases somewhat.

When the grade of the asphalt is increased from PG 76-22 to PG 76-28, the cost of the asphalt per ton of mix continues to increase somewhat. However, the number of cycles per mm of rut depth drops dramatically, almost to the value that was observed for PG 64-22. It is assumed that the APA with steel wheels is also sensitive to the softer PG grade of the base asphalt.

Graph 14

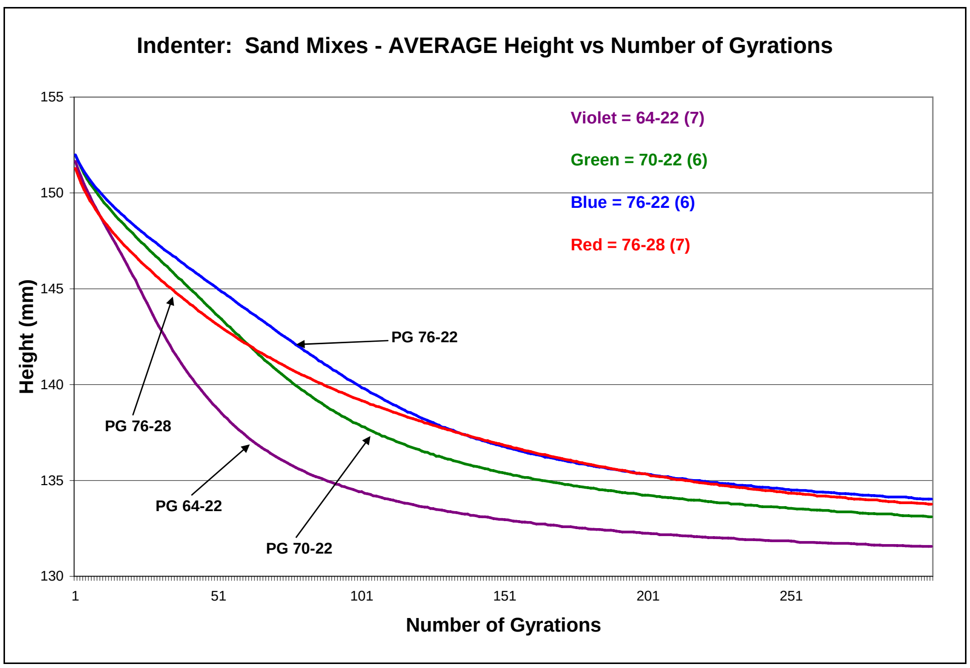


Because of the nature of the Indenter test, with continuous readings throughout the test, it is somewhat difficult to evaluate the costs of changing the PG grade by looking at only the “ending value” from the Indenter testing.

However, the results shown in Graph 15 indicate that when the asphalt grade is increased from PG 64-22 to PG 70-22 and from PG 70-22 to PG 76-22 the rutting performance of the mix improves. This improvement in performance supports the additional costs.

The results shown in Graph 15 also indicate that the rutting performance of the mix is reduced somewhat when the asphalt grade is increased from PG 76-22 to PG 76-28 making the additional cost of increasing the PG grade questionable if the increase in PG grade is intended to enhance resistance to rutting.

Graph 15



Summary

When the asphalt grade is increased from PG 64-22 to PG 70-22 there is a significant improvement in the results of all 5 tests, relative to rutting resistance. This indicates, based on these tests, that the additional cost of $6.49 per ton of mix is justified.

When the asphalt grade is increased from PG 70-22 to PG 76-22 there is a significant improvement in the results of 4 of the tests. The APA with a steel wheel showed essentially the same value for both grades. This indicates that the additional cost of $1.30 per ton of mix is also justified based on these lab test results.

When the asphalt grade is increased from PG 76-22 to PG 76-28 there is improvement, relative to rutting resistance, on only 2 of the 5 tests. The lack of improvement most likely can be attributed to the softer base asphalt used to make the PG 76-28. The lack of test result improvement indicates that the benefit of the additional cost per ton of mix of $1.73 may be questionable. If thermal cracking and the low PG temperature are of concern, then the additional cost of PG 76-28 may prove to be beneficial.